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*Design to Thrive*



## Low Carbon Daylighting Design: Proposal of an Innovative Daylighting Ceramic Facade System

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**Abstract:** This study is focused on the design of an innovative Daylighting Ceramic Façade system (DCF) that explores the potentials of an anidolic profile implemented within a ceramic block in order to improve the illumination distribution of deep plan office buildings. The proposed system combines three key design decisions: the use of ceramics as a low impact material, the optimisation of daylight distribution, and the advantages of prefabricated building construction systems. This paper describes the first stage of the study, in which the DCF system's shape was designed and its daylighting performance evaluated. A ray tracing method was used to define the DCF system's profile, taking into account only direct sunlight and specular reflection. Having defined the optimised section of the profile, the whole system was finalised as a stackable thermally efficient facade system. Daylighting simulations in a full-scale room were conducted to assess the system's effect on indoor daylighting levels and distribution, as a first step to obtain a proof-of-concept. The results show that the DCF system would enable adequate daylight distribution, generally outperforming the reference cases.

**Keywords:** daylighting, innovative, facade, ceramic, anidolic

### Introduction

Maximising daylight use in deep-plan office buildings is a current design challenge in order to decrease energy consumption in connection with lighting, heating, and cooling (European Commission Energy, 2016). Daylighting technologies help to reduce electrical lighting use (currently responsible of 20-60% of the building's energy consumption) (Bodart and De Herde, 2002), manage solar gains, and provide an efficient and healthy luminous environment (SHC Task 31, 2015), but most of the materials and processes involved in the development of these technologies have in turn high embodied energy and carbon, exerting a critical impact on our natural environment (Harris, 1999). It is therefore crucial to research the implementation of low-impact materials in the design of daylighting systems. Clay can play a key role in this endeavour. An extruded clay brick has an embodied energy of 3 MJ/kg, whereas materials typically used in the production of daylighting technology, such as aluminium and acrylic, have an embodied energy of 214 MJ/kg (extruded profile) and 90.67 MJ/kg respectively (Hammond and Jones, 2008). A number of other attributes contribute to characterise clay as an ecological material: it provides high thermal mass capacity, does not 'off-gas', is fully recyclable, very durable, easily accessible, and its surface can be treated with lead-free, non-toxic, germicidal, self-cleaning, free volatile organic compounds, and pollution capturing finishes (Urbano Gutierrez and Wanner, 2016). The use of prefabrication as a production process can further optimise the ecological profile of building components. Production off-site, in a well controlled environment, allows for numerous energy-efficient

benefits: accurate and less wasteful construction, more precise weather-tight joints, faster assembling and disassembling processes, decreased use of raw materials and energy, and a more efficient and cleaner atmosphere around the construction site (less traffic, waste, dust and pollution).

This project's main objective is therefore to investigate an efficient combination of these three sustainable aspects, proposing daylighting control integrated within a façade modular solution, based on the use of clay and prefabrication as a low carbon strategy. This paper introduces the first developmental stage of a Daylighting Ceramic Façade (DCF) system, whose fundamental goal is to offer in one single compact solution optimised daylighting performance, minimised ecological footprint, and an efficient structural façade system.

## Description of the System

The DCF façade system is a vertical array of ceramic blocks that collect and redirect incoming light through an internal channel deep in the interior of the building. This channel follows a profile composed of four reflective surfaces, which splits the ceramic block into two parts: the top part contains surfaces B and C, and the lower part contains surfaces A and D (Figure 1). This profile departs from the geometry and proportions used in an existing louver system based on a zenithal anidolic collector and a compound parabolic collector (Thuot and Marilyne, 2014), that has been further adjusted. Two glass panes seal the channel towards the outside and inside environments, bringing structural integrity to the block and generating an independent insulated façade building unit. The sealed glazing provides protection from dust and scratching of the internal optical surfaces, ensuring the proper operation of the system and reduced maintenance. Argon gas and other alternative insulating materials can be inserted in the block to further increase its insulating capacity, which will be the focus of a second stage of this study.

To protect users from glare, there should be no view through the ceramic element towards the outside. Consequently, the system is envisioned to be located above eye level, in the upper part of the south façade, with its bottom part no lower than approximately 2.1m from the floor, to allow for clear visual contact with the outside in the area underneath the system.

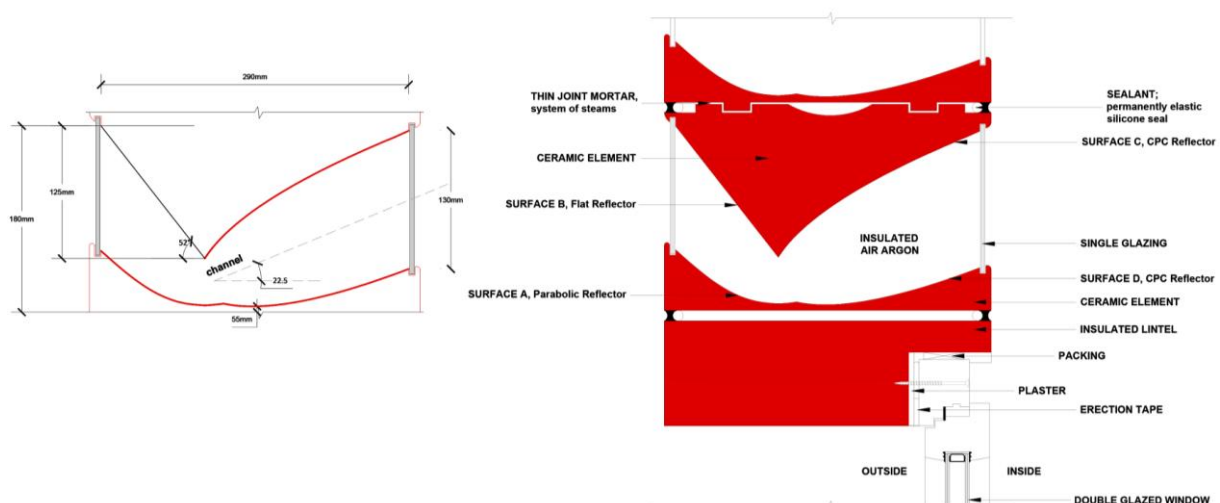


Figure 1. Daylight Ceramic Façade system (DCF)

## Methodology

This paper presents the DCF system's daylighting performance in comparison to two reference cases. A ray tracing method using Ecotect was used to define the DCF system's profile while computational simulations using DesignBuilder have been used to predict its daylight performance. The design conditions were set taking into consideration both optimised daylighting performance and a contemporary office building setting –sidelit deep plan space, alongside appropriate response to the predominantly cloudy skies with low sun altitudes of Liverpool, in the UK.

All the profiles' sections were assessed for the 53°25'12"N latitude at 12:00-13:00 pm with the system facing south. The lighting performance of each ceramic profile has been assessed in summer and winter solstices, and autumn and spring equinoxes, using 2° intervals. Light incidence angles at solar noon for each of the four situations are shown in Table 1.

Table 1. Solar altitude/angles (elevation angles) of Liverpool, UK

City location	Maximum solar altitude/angle	Minimum solar altitude/angle	Equinox solar altitude/angle
	21st of Jun., 1PM	21st of Dec., 12PM	21st of Mar., 12PM 21st of Sep., 1PM
Liverpool	60°	13°	36°

### DCF Profile's Design

The first half of the channel was defined first, with the aim to capture as much light as possible: surface B as a flat reflector, and surface A as a parabolic reflector. According to the reference system, the ideal minimum angle of a flat reflector is 45° with respect to the horizontal plane, so that any incoming light with an elevation angle  $\alpha$  of 0° or greater could pass through the daylighting system. In this system the angle of surface B had to be 58°, due to the louver's construction needs. As a result, the majority of incoming light rays at less than 27° are rejected, which is a negative consequence for our location. As anticipated, an angle of 45° in surface B in our system also proved to be more efficient than an equivalent profile with an angle of 58° (Figure 2).

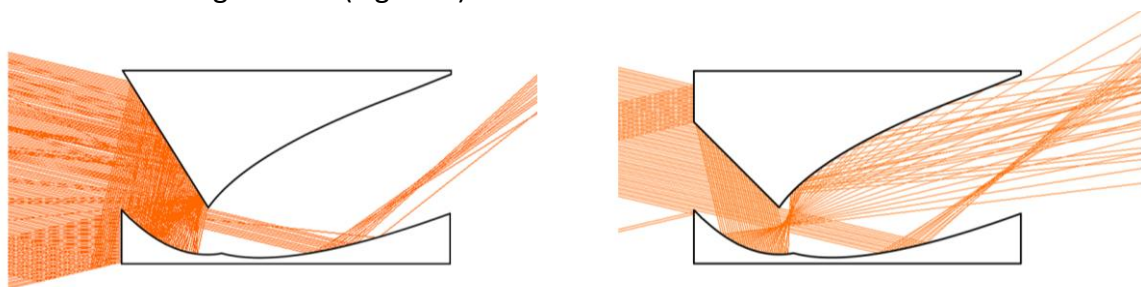


Figure 2. Comparison of the ray-tracing patterns when angle of surface B is 45° (Right) and 58° (Left) above the horizontal plane, at 53°25'12"N latitude at 12:00PM in the winter solstice (13°)

In order to obtain a more effective system, another parameter had to be examined. It is obvious that any changes in the angle of surface B have direct impact on surface A, in order to maintain the geometric proportions of the profile. Specifically, as long as the angle of surface B is equal to the ideal minimum angle, the parabola of surface A becomes excessively long, increasing the opaque part of the system to an extent that fails to conduct sufficient daylight. For this reason, the angle of surface B is ideally greater than 45° and

lower than  $58^\circ$ . Furthermore, taking into account that the proposed system is a permanent structural design element of the building, its depth was set at 30cm. To meet this dimension, the selected angle of surface B must be  $52^\circ$ . To confirm the efficiency of this angle, we looked at the ray tracing diagrams, which showed how all the incoming rays with elevation angles between  $13^\circ$  and  $60^\circ$  are deflected by the system and none exit the channel at an angle less than  $0^\circ$  above the horizontal plane (Figure 3). However, the majority of light rays coming in at less than  $10^\circ$ , defined as cut off elevation angle, are partially or completely blocked by the system, which were regarded as acceptable losses. Thus, surface B was defined at an angle of  $52^\circ$ .

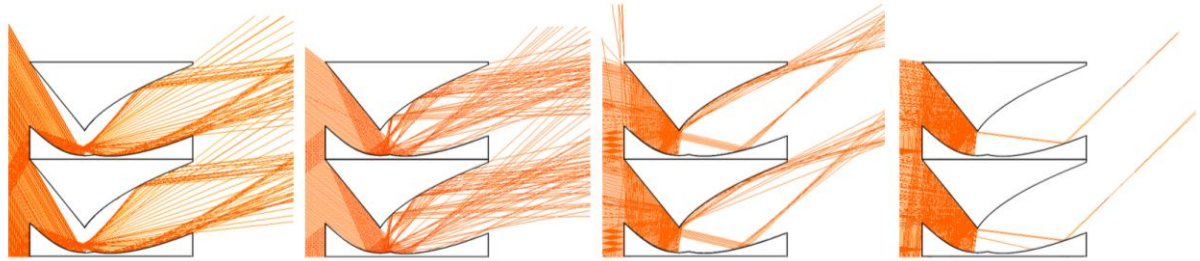


Figure 3. Ray tracing through proposed system for incoming elevation angles:  $60^\circ$  - summer solstice (1st),  $36^\circ$  - spring and autumn equinox (2nd),  $13^\circ$  - winter solstice (3rd) and  $10^\circ$  - cut-off elevation angle (4th)

For the second half of the channel, special consideration had to be given to the upward rotation angle of the CPC profile (surfaces C and D). In the reference case, the CPC profile was rotated upwards by  $20^\circ$  (maximum output angle). In our proposal, the rotated angle of the CPC profile is slightly higher, reaching  $22.5^\circ$ ; therefore, the output angle is between  $0^\circ$  and  $45^\circ$ . By doing this, the system is adapted to the needs of a 9m deep room, and it is assumed that each individual space conditions will have an impact on final adjustments in the system.

The following ray tracing diagrams show that in our case, with an output angle between  $0^\circ$  and  $45^\circ$  above the horizontal, the light was distributed in a larger area, in contrast with the reference case, in which a large portion of light is less dense near the ceiling. Although the difference might seem negligible, the CPC's  $22.5^\circ$  angle was integrated in the final profile.

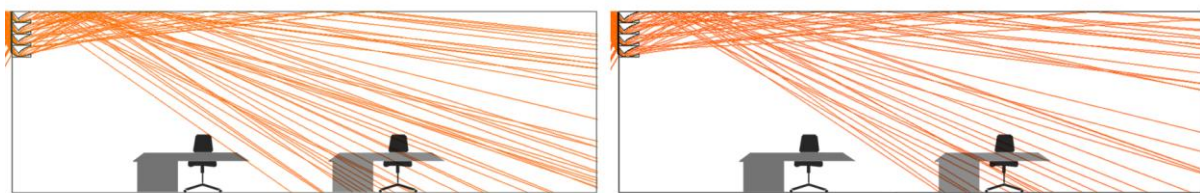


Figure 4. Distribution of daylight in a 9m deep room: outgoing angle  $0^\circ$  -  $40^\circ$  in the reference case (Right) and outgoing angle  $0^\circ$  -  $45^\circ$  (Left)

### **Model Description**

Lighting simulations were run to get illuminance results for a generic south-facing room (9m deep x 4m wide x 2.8m high), with the full daylighting system operating. The system was compared to two reference cases (Figure 5). The room was defined as sidelit only, therefore all the walls other than the south facade were modelled as completely opaque.

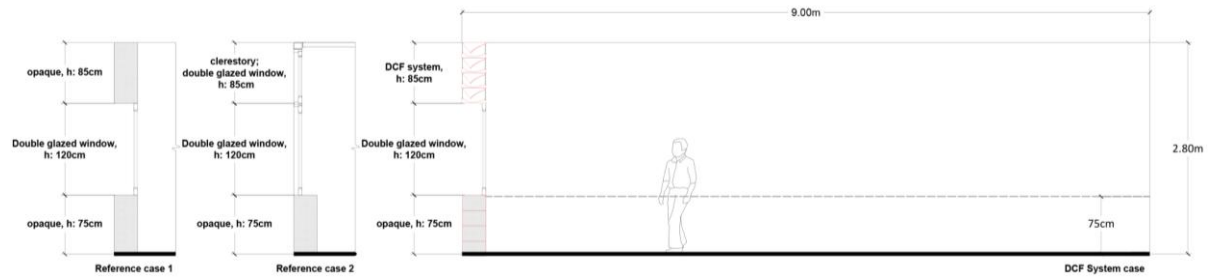


Figure 6 Sections of the model rooms

All cases were examined under totally overcast sky conditions, partly cloudy sky (intermediate day) in summer solstice and spring/autumn equinox, clear sky in winter and summer solstice, as well as in spring/autumn equinox, considering the building's south façade has an unobstructed view of the sky. The intermediate sky in winter solstice can be disregarded since in Liverpool during the winter months the average sky cover is approximate 13.5 hours a day (Energy Plus, Liverpool's weather data). On the other hand, the clear sky in winter solstice is presented typically, in order to examine the system in low sun altitude. Illuminance values are reported on a workplane at 0.75m from the floor, along the centreline of the room moving away from the south facade. Additional modelling details are provided in Table 2.

Table 2. Model Parameters

Wall Reflectance; white paint	70%
Floor Reflectance; wood finish - light colour	35%
Standard Ceiling Reflectance	60%
Window Transmittance (Double glass unit)	70%

## Results and Discussion

Considering the recommended illuminance of 300–500 lux evenly distributed for office work (CIBSE, 2015), and given that the proposed system was designed mostly to increase light levels in the deeper part of the room, mainly under overcast sky conditions, its daylighting performance is deemed successful (Figure 7). Regarding the sunny cases, it is obvious that the system performs better for depths of 2m to 3m and greater compared to conventional facades, however occasional support from blinds may be needed. In particular, in the overcast case, the proposed system outperforms both reference cases at distances of 3m or greater from the daylit facade, reaching an average illumination of approximately 250 lux (Figure 7). On the other hand, the reference cases present an excessively high illuminance in the area near the window, which reaches 900 lux or more, while for a distance over 3m from the daylit facade, the illumination levels drop sharply reaching 100 lux or even less.

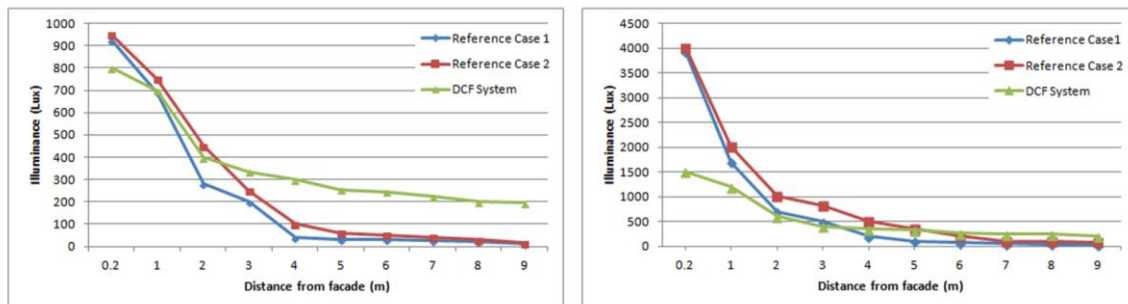


Figure 7. Overcast case (Left) and Partly Cloudy case: 21<sup>st</sup> June at 13:00 (Right)



For situations where the sky is partly cloudy (intermediate day), 21<sup>st</sup> of June at 13:00: Figure 7 shows that the DCF system shows a very efficient performance, with illumination levels varying between 600 – 250 lux in distances further than 1.5m from the daylight facade, providing also a homogeneous illumination more likely to provide visual comfort. The results seem even better if compared with Reference Case 1, in which for depths of 4.5m or greater, the illumination levels are less than 150 lux. Compared with Reference Case 2, the system seems to perform better only for depths of 6.5m or greater.

For the partly cloudy case, autumn/spring equinox at 13:00 (Figure 8), the DCF system always performs better than both standard glazing facades for depths of 4.5m or greater. Unfortunately, it also presents particular high illumination levels in the area near the window (<1m), because of the quite big uncovered glazing area of the model room. Certainly, both reference cases present uncomfortable peak illuminance near the window - more than 4500 lux. Clearly, the effect is more intense in Reference Case 2.

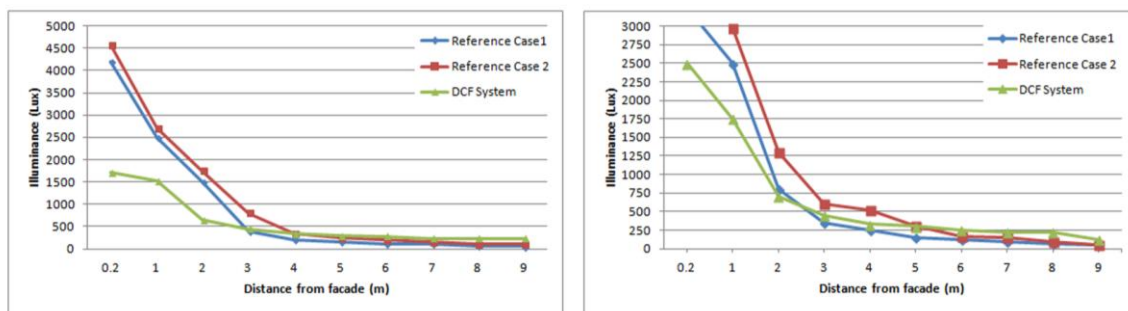


Figure 8. Partly Cloudy case: Autumn/Spring equinox at 13:00 (Left) and Sunny case: 21<sup>st</sup> June at 13:00 (Right)

For a sunny sky on 21<sup>st</sup> June at 13:00, the DCF system outperforms the Reference Case 1 for depths of 3.5m or greater, but it matches the Reference Case 2 only for depths of 5m to 6m. The DCF's performance is slightly better for depths of 7m or greater, with illumination levels of approximately 200 lux. In general while the system performs well for the rear area of the room, the uncovered window disturbs the uniformity illuminance of the space resulting from direct sunlight transmission (Figure 8). In the sunny case on 21<sup>st</sup> March at 12:00pm, the DCF system provides acceptable illumination levels which range between 500 - 200 lux for depths of 3m or greater (Figure 9). The sunny case on 21<sup>st</sup> December at 12:00pm, presents the worst of the results. This is the only case in which the DCF system performs worse than Reference Case 2; only for depths of 7m or greater, the DCF system matches Reference Case 2 performance. These results were expected, as already seen in the ray tracing diagram for the winter solstice, a high proportion of the radiation is not accessing the system.

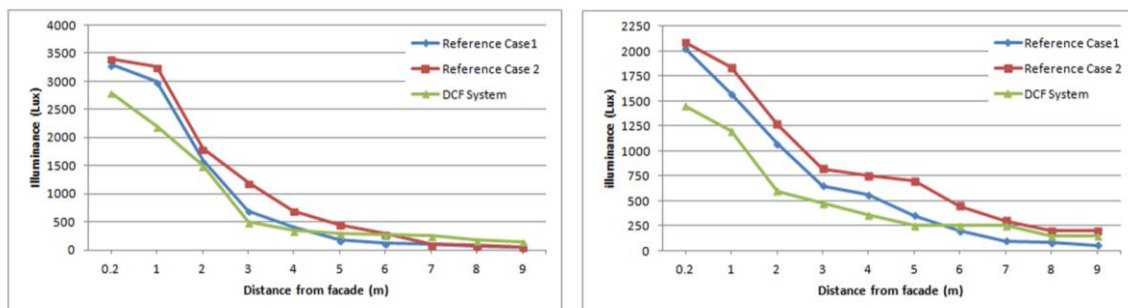


Figure 9. Sunny cases: 21<sup>st</sup> of September at 13:00pm (Right) and 21<sup>st</sup> of December at 12:00pm (Left)

## Conclusions

As shown from the daylighting analysis, the proposed system successfully collects daylight with the outer part of its profile, and redistributes it with its inner part to the deep gloomy zones of the room. The DCF system, when compared to two conventional façade configurations, shows a more efficient performance improving lighting levels where required, mainly under cloudy and sunny conditions. Homogeneous illumination throughout the space is observed only for cloudy conditions, as the system presents peak illuminance near the window (<1m) for sunny cases. The study presents several limitations. It is focused on the design of the DCF system based on daylighting performance, and assessed for only one space with one orientation in one climate zone, Liverpool's sky type and sun altitude. Therefore, more testing with different locations, latitudes and building shape could confirm the universality of the proposed system. However, it could be argued that it might be an efficient solution for a sufficient number of UK and other Central and Northern Europe areas with similar sky conditions. To confirm these results, a subsequent step will be to undertake a more extensive evaluation, running annual on hourly base simulations, as well as looking at daylight sufficiency assessment, such as continuous daylight autonomy and useful daylight illuminance. The DCF system was assessed in relation to clear conventional glazing (both reference cases). However, in practice, most offices have their glazing areas shaded with blinds in order to avoid direct solar heating in summer and act as a glare protection screen. Therefore, additional modelling could be done comparing the system with standard venetian blinds. The DCF system is envisioned as a structural building component, forming part of a walling system using piling blocks. As such, other critical environmental parameters will need to be assessed: thermal performance, ecological profile, and cost. DesignBuilder was chosen because it provides a single digital environment to obtain preliminary simulation results for all of these parameters, planned for the next step of this project.

## Acknowledgements

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